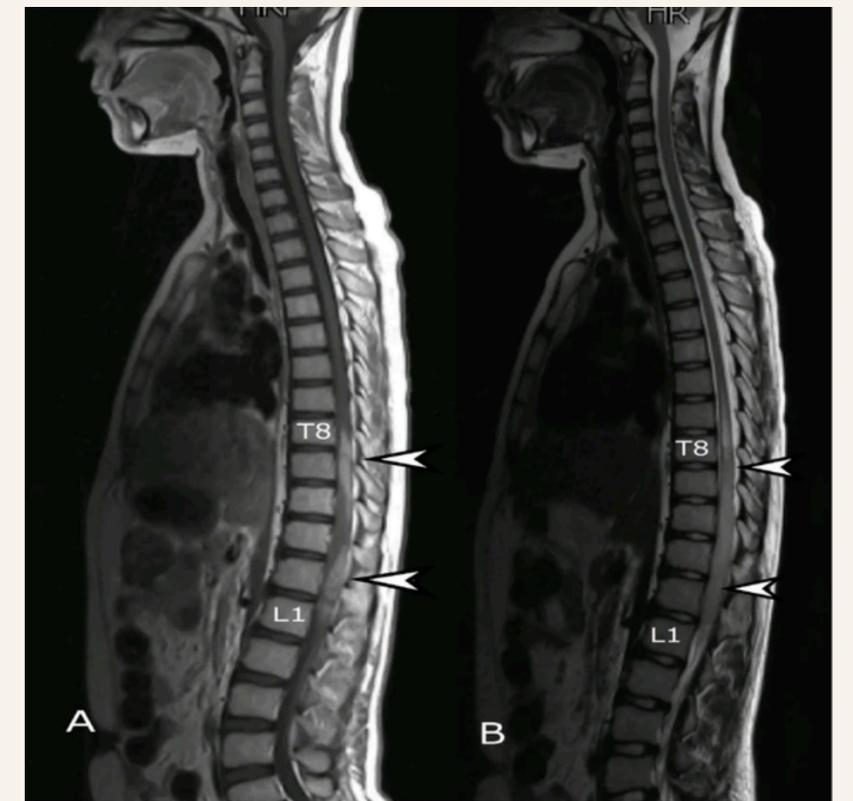
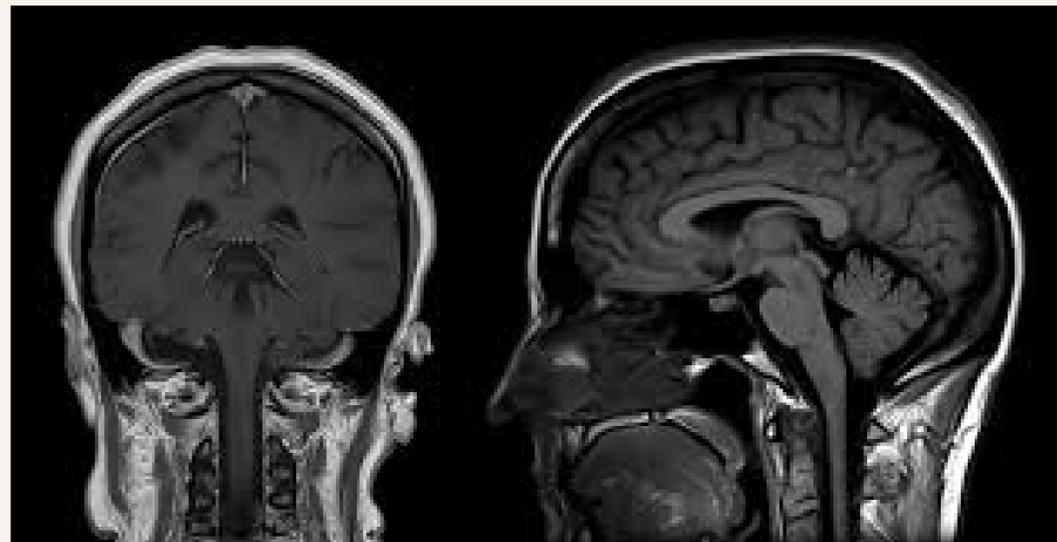
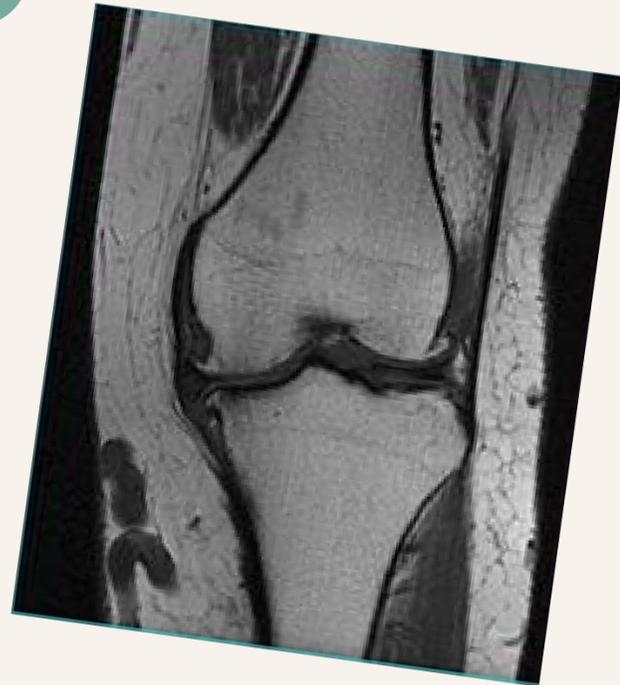


Magnetic Resonance Imaging (MRI)

PHYSICS OF MRI



Wen Yin, Kar Roong 403



What is MRI?

Magnetic Resonance Imaging (MRI) is a non-invasive medical imaging technique that leverages the principles of nuclear magnetic resonance (NMR) to generate high-resolution images of internal structures, particularly soft tissues.



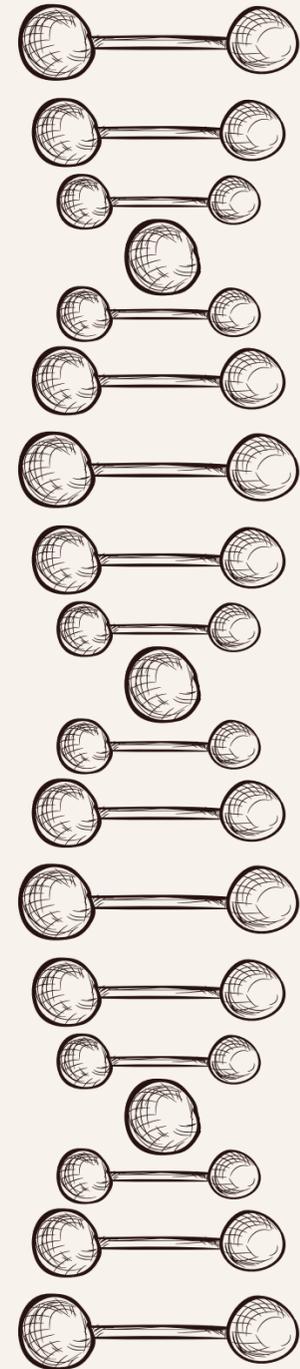
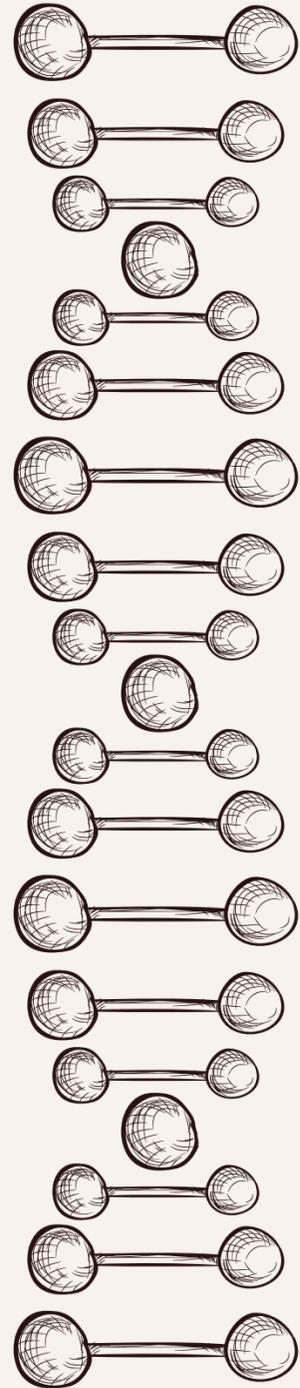
History of MRI

Discovery of nuclear magnetic resonance (NMR) in 1946
(by Felix Bloch and Edward Purcell)

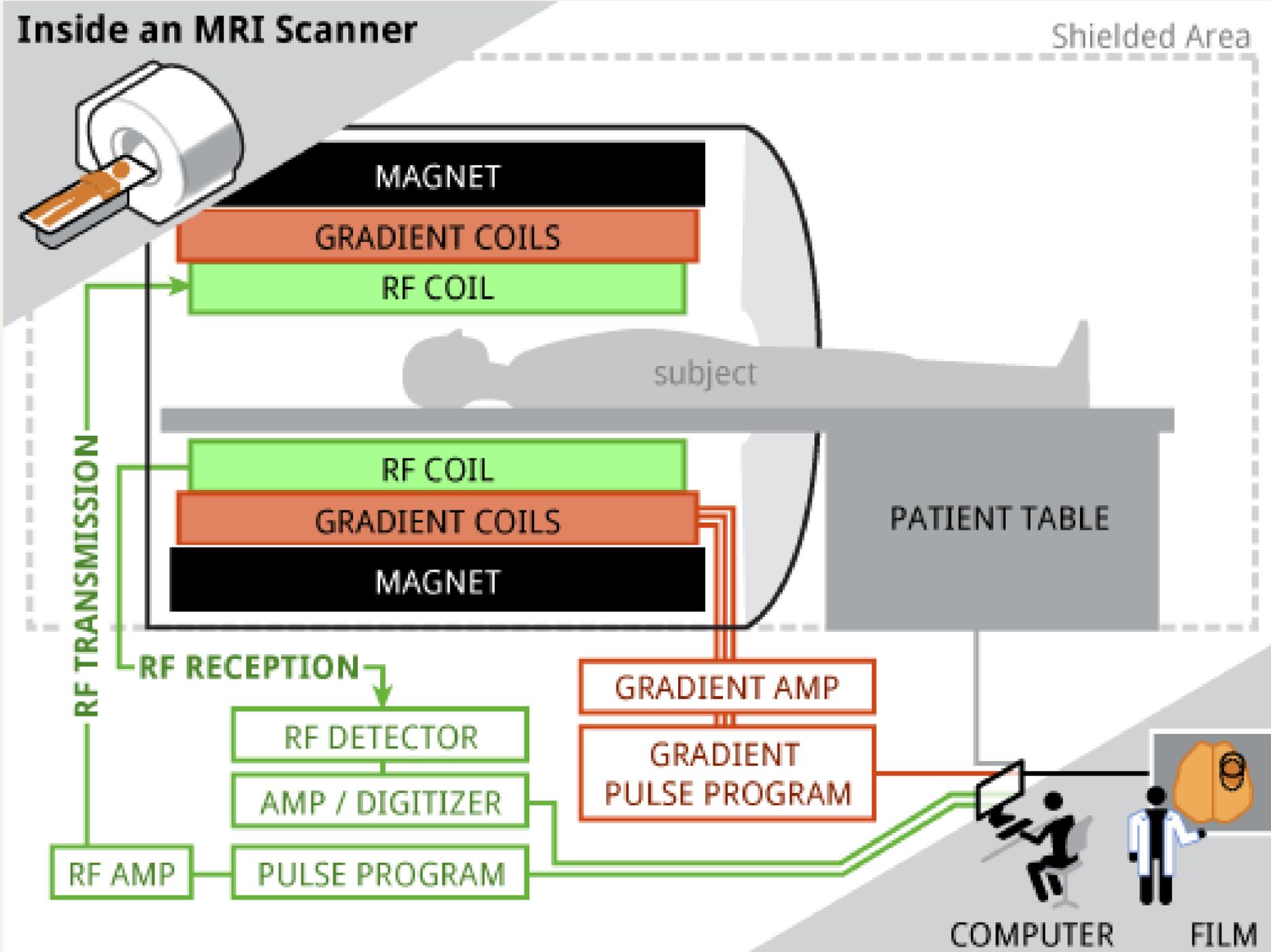
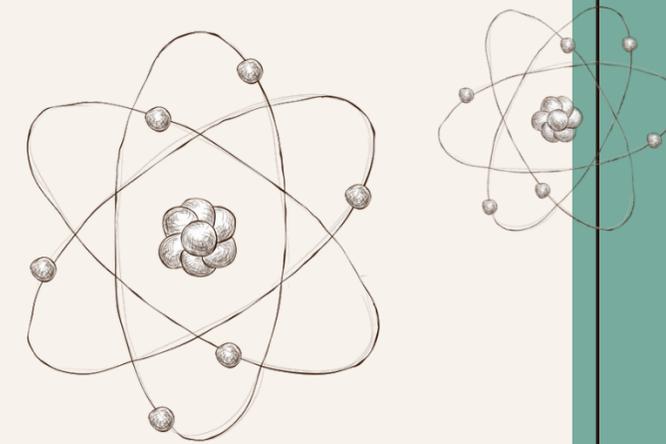
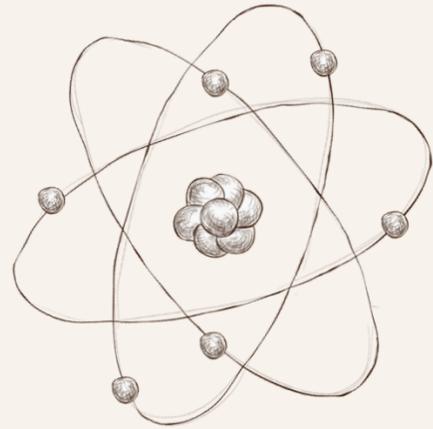
- demonstrated how atomic nuclei absorb and re-emit electromagnetic radiation when placed in a magnetic field

Spatial encoding in 1970s (by Paul Lauterbur)
through magnetic field gradients

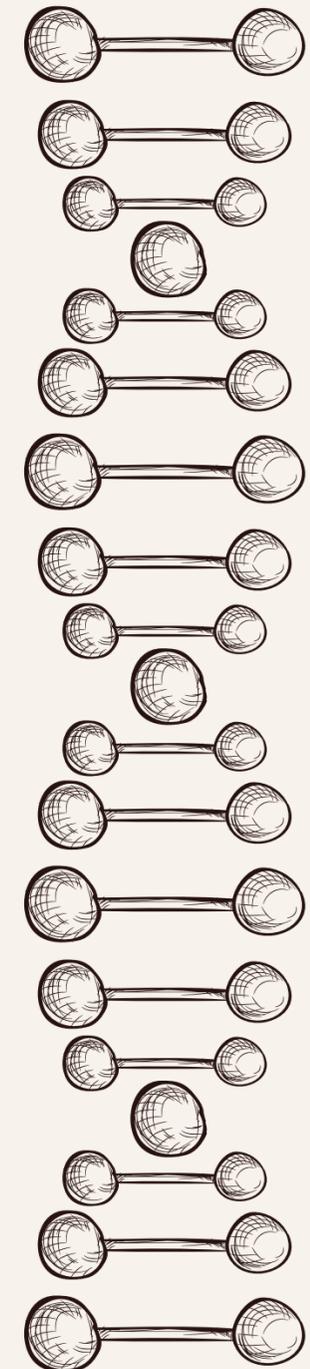
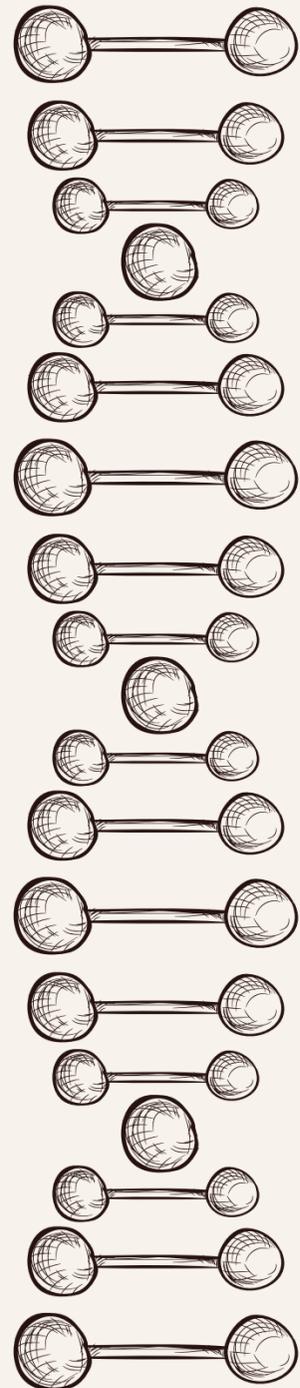
Rapid Imaging Techniques 1970s (by Peter Mansfield)



Components



How does a MRI machine work?



Hydrogen atoms & Spin

The human body contains an enormous number of hydrogen protons.

These protons possess intrinsic magnetic moments due to their spin.

- In the absence of an external magnetic field, the tiny magnetic moments of hydrogen atoms are randomly oriented and cancel out (Fig.1).
- However, in a very strong magnetic field (B_0), proton spins align parallel (low energy) or anti-parallel (high energy)(Fig. 2). This slight excess in the parallel state produces net magnetization along the field direction.

The frequency of precession of these protons is the Larmor frequency (ω_0), where γ is the gyromagnetic ratio :

$$\omega_0 = \gamma B_0$$

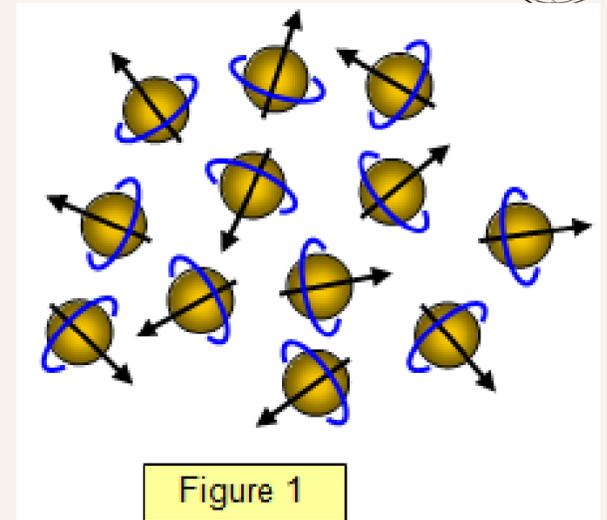
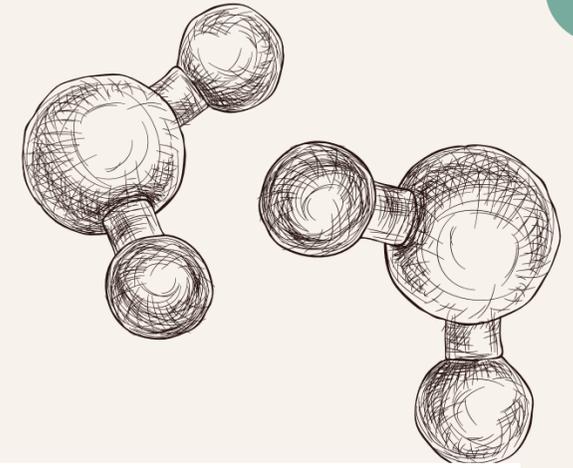


Figure 1

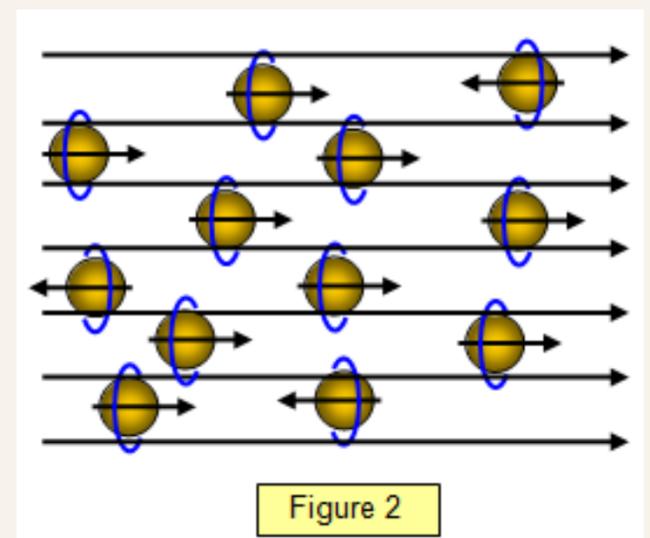
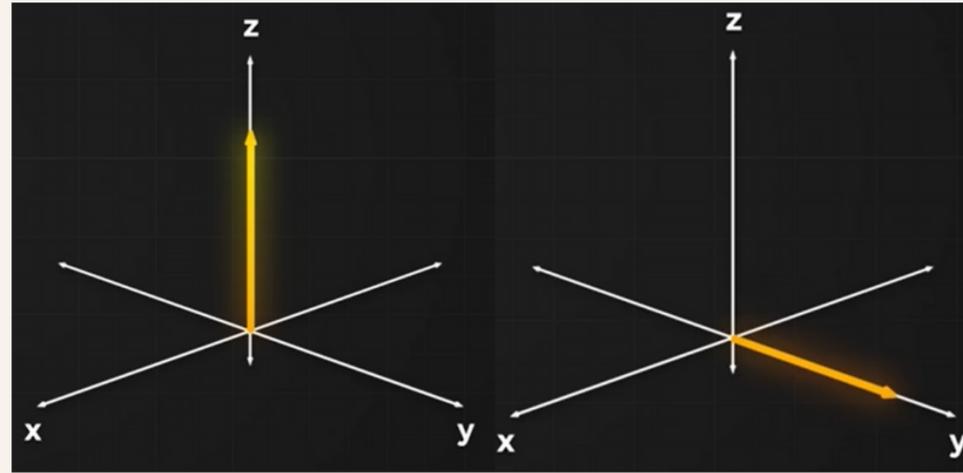


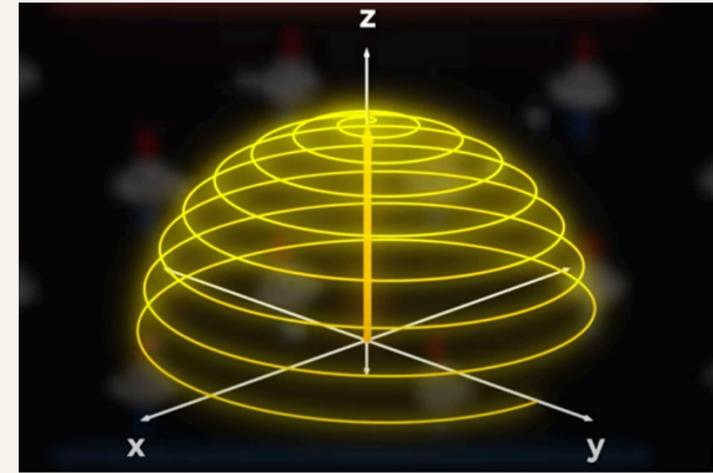
Figure 2

RF



Excitation

- RF coil is on and sends magnetic radiofrequency pulses tuned exactly to the Larmor frequency.
- This misaligns the hydrogen to be perpendicular to the large magnetic field (along the z-axis) into the transverse plane.



RF

Relaxation

- When RF coil is off, the spins relax back to alignment.
- They fall back to their equilibrium state in a spiraling manner.
- Hydrogen nuclei lose the energy they absorbed during excitation.
- The process induces a current in receiver coils → measurable signal (via Faraday's Law of Induction).

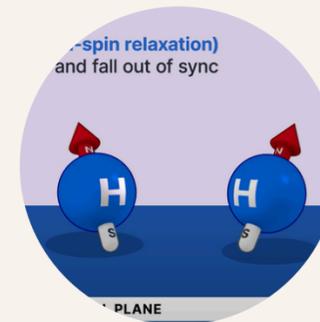
Relaxation Mechanisms



- **T₁ relaxation (spin-lattice)**

Recovery of longitudinal magnetization as energy is exchanged with surrounding molecules

as protons lose energy from the pulse to the lattice, they increase their magnetisation and return to their longitudinal plane



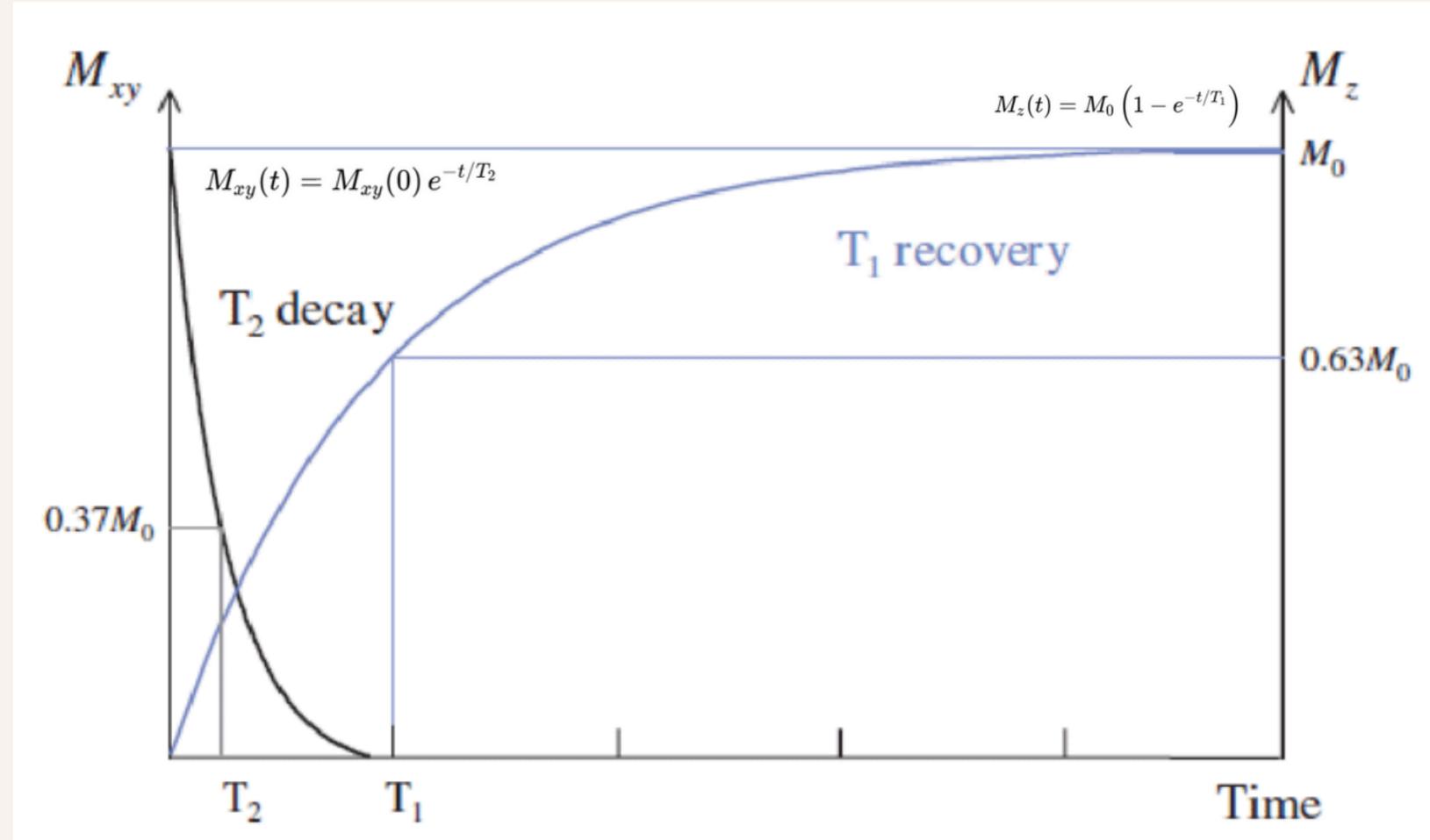
- **T₂ relaxation (spin-spin)**

Decay of transverse magnetization due to dephasing of spins

interaction of hydrogens with each other due to the absence of RF pulse cause them to lose their synchrony (spins dephase → reduction in magnetisation in the transverse plane)

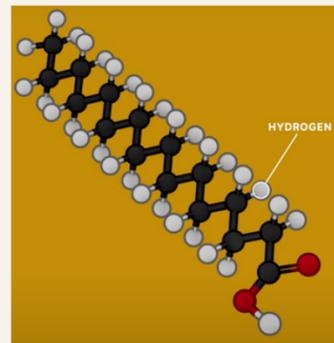
RF Relaxation

- spin-lattice and spin-spin relaxation occur simultaneously but independently
- different tissues have different relaxation times, hence creating an image contrast



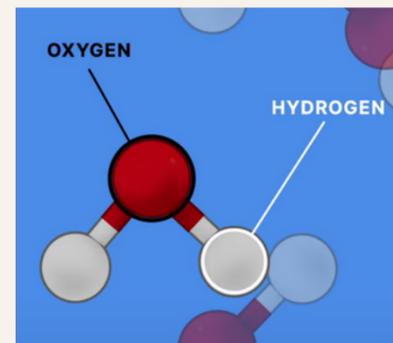
T_1 is generally longer than T_2 (differs for different tissues), affecting the image quality and contrast

T₁-weighted Image



Fats

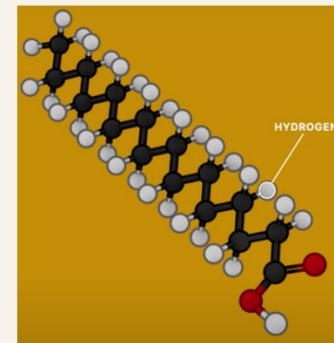
- takes a shorter time to recover
- more longitudinal magnetization available to be flipped into the transverse plane
- stronger signal
- brighter image



Water

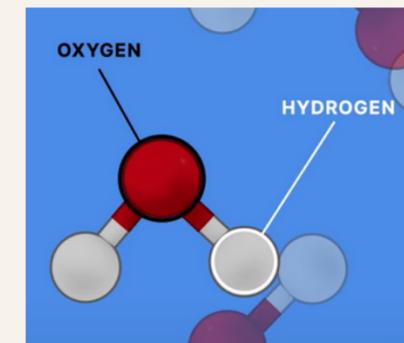
- takes longer to recover
- less longitudinal magnetization available to be flipped into the transverse plane
- weaker signal
- darker image

T₂-weighted Image



Fats

- high density of hydrogen nuclei
- high energy transfer efficiency
- takes a shorter time to dephase
- lower signal
- darker image



Water

- low density of hydrogen nuclei
- transfer energy less efficiently
- takes longer to dephase
- higher signal
- brighter image

Gradient coils and spatial encoding

Gradient coils are electromagnets that create controlled variations in the magnetic field along x, y, or z directions. (Fig.3)

This means that Larmor frequency now also depends on position:

$f(x) = \gamma(B_0 + G_x \cdot x)$, where G_x is the gradient strength along the x-axis.

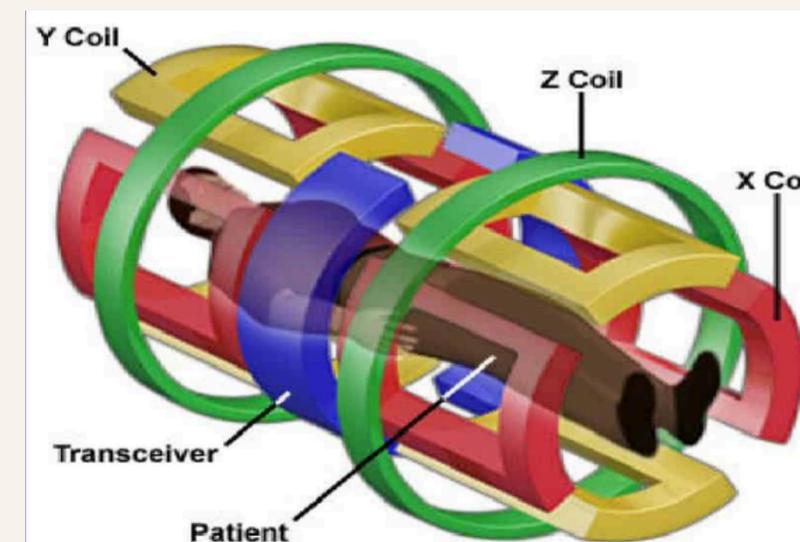


Fig.3

→ Slice selection: RF pulse tuned to the frequency at one location → excites only that slice.

→ Within-slice localization:

- Frequency encoding: gradient makes spins precess at different frequencies → distinguishes positions along one axis.
- Phase encoding: gradient along the perpendicular axis shifts proton phases → combined with frequency encoding, locates every point.

Fourier Transform & Image Formation

MRI signals recorded in k-space, which is a frequency domain (fig. 4)

→ This is simply a complex mix of all proton signals in a slice, not an image

Fourier Transform converts frequency data into a spatial image by breaking down the complex signals into simpler wave patterns. (fig.5)

- Gradients create stripe patterns that encode spatial positions.
- Combining all patterns mathematically → the final grayscale image emerges.

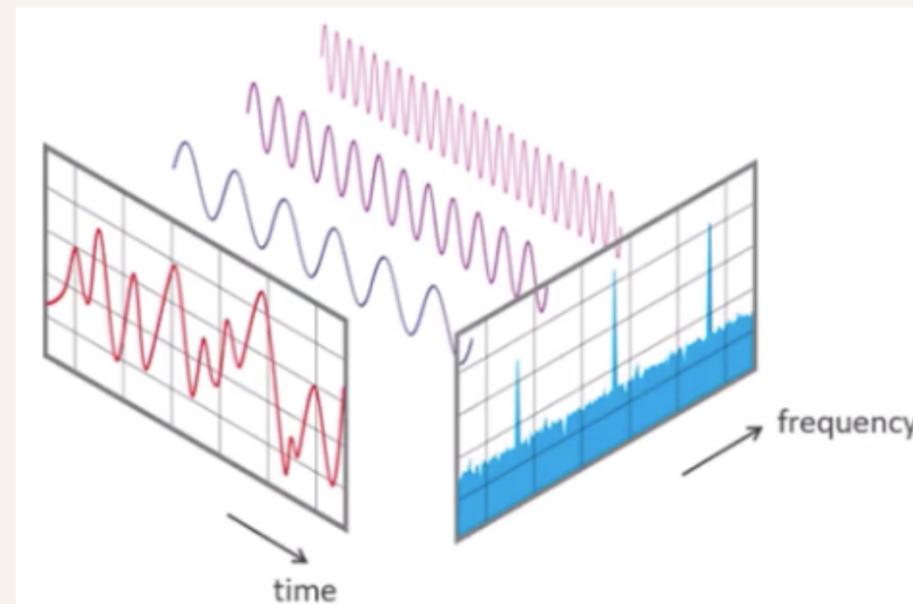


fig. 5

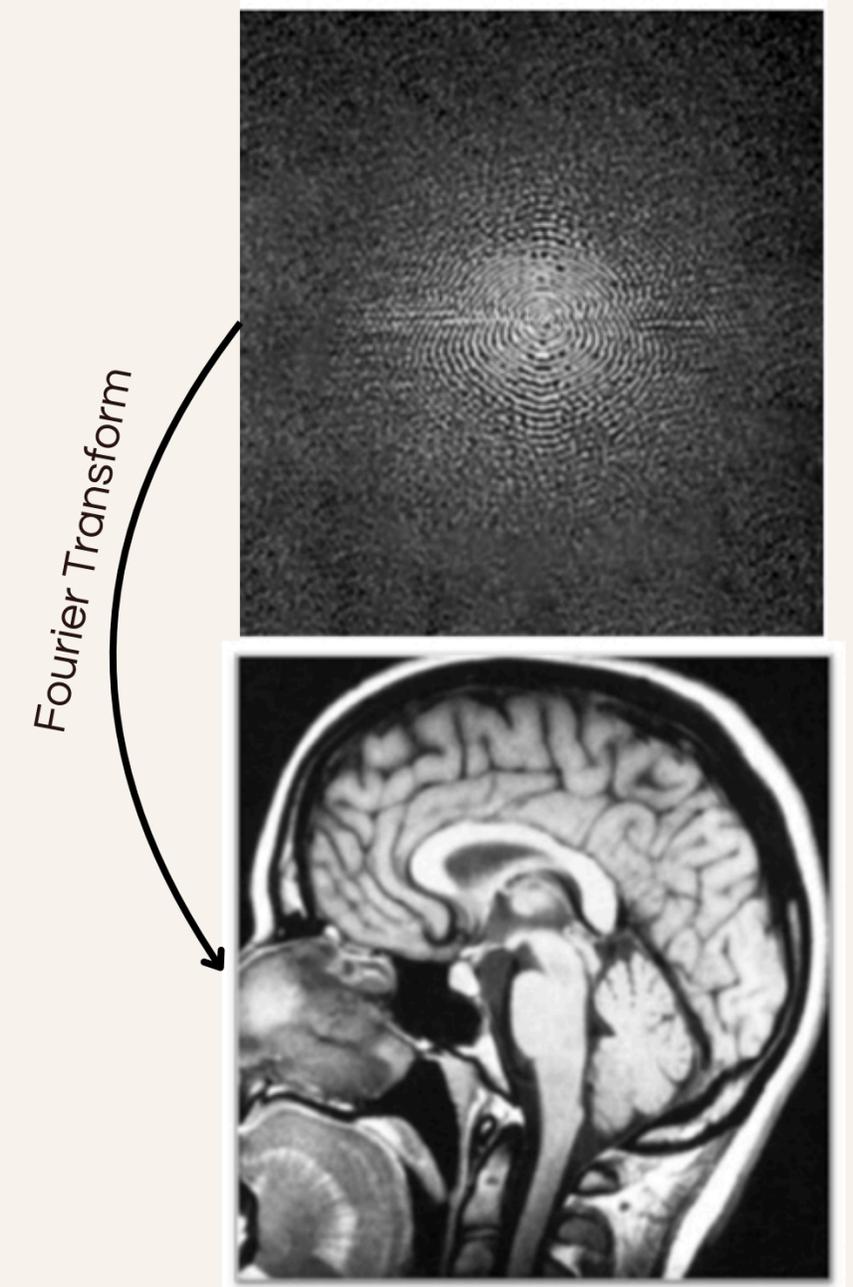
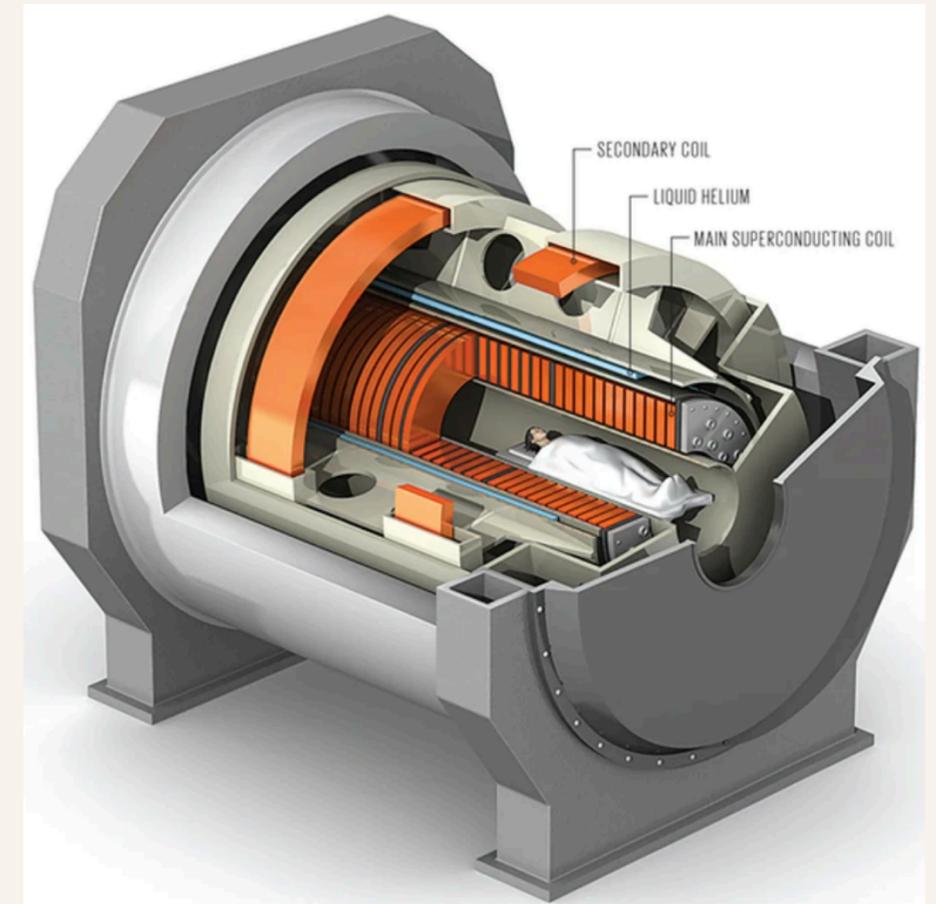


fig. 4

Superconducting coil

To produce such strong, stable magnetic fields, very large electric currents are required, which would overheat ordinary wires. Thus, modern MRI machines use superconducting electromagnets (niobium–titanium wire) cooled close to absolute zero.

- At these temperatures, the wires have zero electrical resistance. This means enormous currents can circulate indefinitely.
- MRI systems use “zero boil-off” helium technology to achieve these temperatures, where helium is held in a vacuum-insulated chamber and cooled by a cryogenic refrigeration cycle.



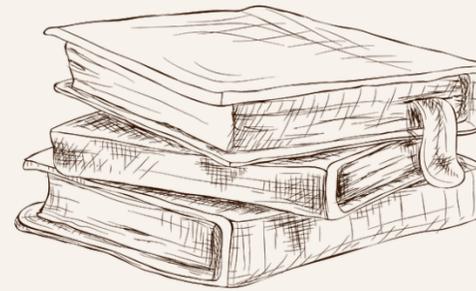
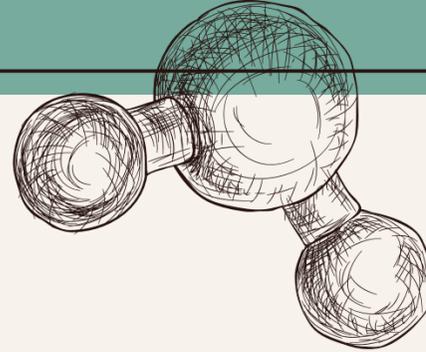
Applications

neurology, orthopedics, cardiology, oncology

- often used to image knee and shoulder injuries

specialised MRI:

- Functional MRI (measures brain activity)
- Diffusion MRI (quantifies diffusion of water molecules)
- Magnetic Resonance Spectroscopy (analyses chemical composition of tissues)
- Hyperpolarised Gas MRI (mainly for lung imaging)



Limitations

- costly
- time-consuming
- motion sensitivity (even slight patient movement can blur the images)

Risks

- MRI machine's strong static magnetic field could turn a ferromagnetic object into a harmful projectile or cause vertigo and headache
- Loud noises produced in the scanner from switching magnetic fields
- Gradients generate varying magnetic fields that can cause peripheral nerve stimulation and muscle twitching

Magnetic Resonance Imaging (MRI)



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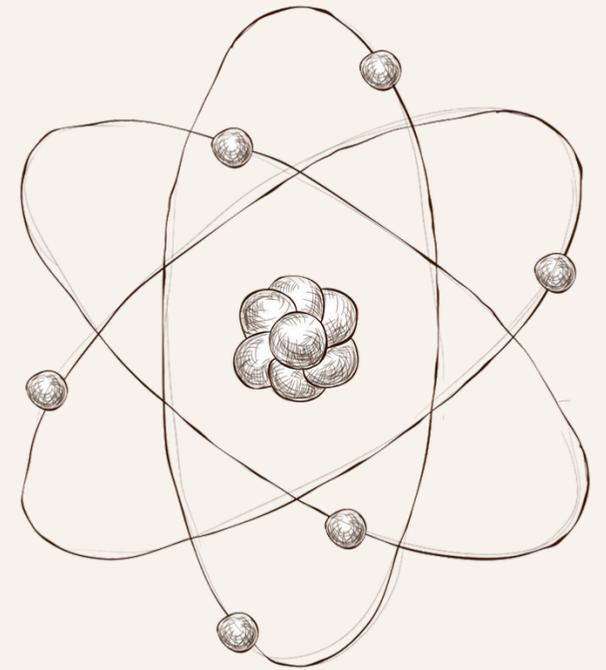
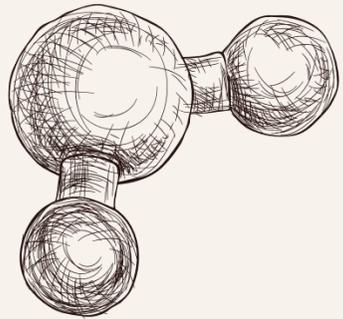
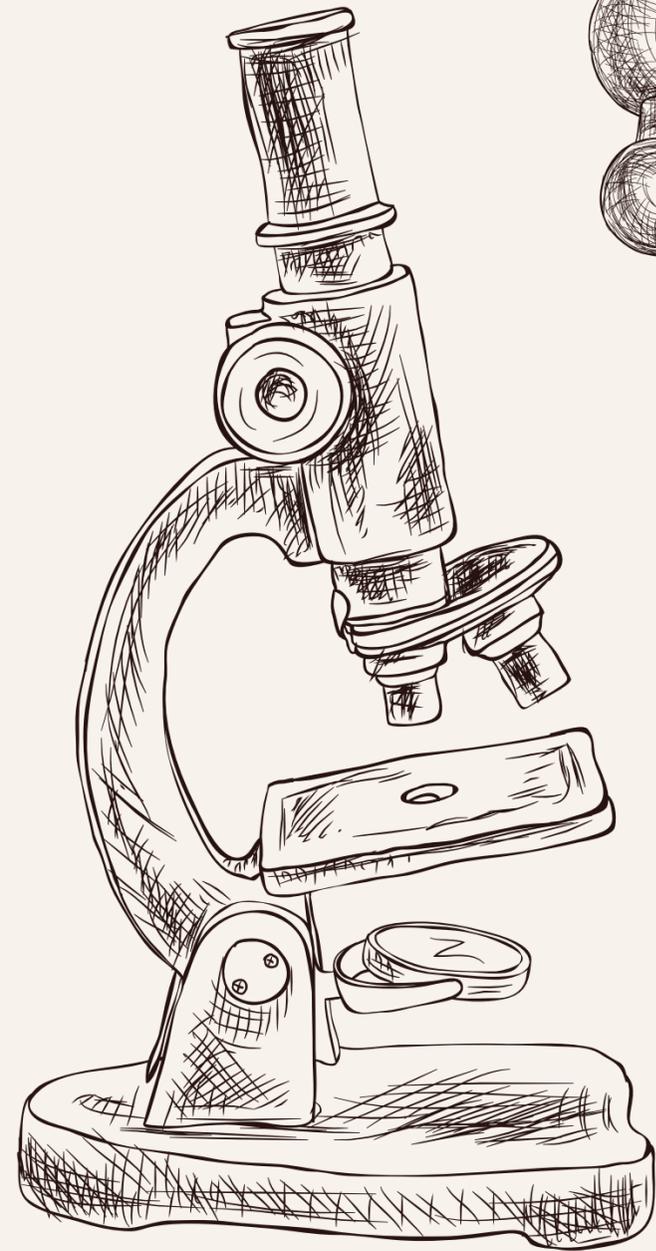
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**Thank
you!**

